Potential reductions in greenhouse gas emissions associated with beef production

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Executive Summary

Current trends show an increase in demand and consumption of beef around the world. As beef production is a large contributor to greenhouse gas emissions, it is important to do as much as possible to reduce these emissions. The main greenhouse gases that are associated with beef production are carbon dioxide, methane, and nitrous oxide.

It is hard to quantify emissions from livestock products because of the many factors involved with production, distribution, and consumption. Because of all these factors, there are many opportunities for reductions in emissions. Some of these opportunities include waste management solutions, changing feed type, and selective breeding. Waste management solutions include covering stored waste, mixing in additives, or moderating the temperature of the stored waste products. Pre-digestion solutions include changing the composition of feed to include higher concentrations of digestible and metabolizable energy, as well as higher concentrations of ash and crude proteins. Another pre-digestion solution is to selectively breed cattle to produce less methane. Reductions in emissions can also be made farther down the production line, in processing, transportation, refrigeration, etc.

Since these solutions may not be enough to cancel out the increases in emissions accompanying increasing population and demand, other solutions may also need to be implemented. These solutions include changing the public perception and demand for beef products, as well as implementing food policy and promoting local beef.

In order to achieve meaningful reductions in greenhouse gases, a multi-faceted approach will need to be taken. With only one solution, there is no chance of achieving the reductions necessary to avoid devastating consequences from greenhouse gas emissions.

Introduction

The Intergovernmental Panel on Climate Change (IPCC) released its most recent climate assessment report on April 13, 2014. Responsible for analyzing the scientific, technical, and socio-economic data relating to climate change, the IPCC concluded that a 40-70% reduction in greenhouse gas emissions is needed by mid-century to avert the worst predicted effects of climate change . Facing the need for such drastic reductions, it is necessary to start analyzing different ways in which climate change can be mitigated. With agriculture accounting for 18-51% (Goodland and Anhang, 2009) of greenhouse gas (GHG) emissions, the possibility for large reductions in this category seem viable. While many variables contribute to the emissions related to agriculture, one large component is the production of beef (Dunkley, 2013). In a life-cycle analysis (LCA) comparing the emissions from beef cattle, swine, and poultry, beef cattle were found to have the highest LCA emissions per kilogram of consumed meat, with 86% of these emissions being attributed to production (Dunkley, 2013).Producers of beef have the opportunity to make changes in their current practices that could result in lower emissions in a short amount of time while having a minimal impact on profits. Unlike government entities, producers have the opportunity to enact swift changes to their businesses, decisions that could have a strong impact on their contribution to climate change.

Unfortunately, changes to current practices in beef production will not be enough to achieve the maximum amount of emissions reduction possible. With the Earth's population projected to surpass 9.6 billion by 2050 (World Bank), the increased demand for meat, and the emissions associated with it, may cause an overall increase in agriculture emissions despite sustainable changes made in beef production systems. Therefore, it is necessary to explore other means of reducing agricultural emissions attributed to beef. This report will analyze ways in which producers of beef can reduce the amount of emissions associated with beef production through waste management, feed selection, selective breeding, and potential solutions associated with beef processing. In addition to these potential mitigation solutions, this report will assess the key elements relating to reducing demand for beef through promotion of a vegetarian lifestyle, using local sources of beef to reduce emissions associated with transportation, and the implementation of policies relating to mitigation and abatement in the agricultural sector. While no one solution can provide the reduction in emissions necessary to halt climate change, a multi-faceted approach may be the answer we are looking for.

Background

Range of Values Attributed to Agricultural Emissions

The percentages of agricultural and livestock contributions to greenhouse gas emissions are highly debated. It is extremely difficult to calculate these numbers because of the large amount of overlap between sources of emissions. In "Livestock and Climate Change" by Robert Goodland and Jeff Anhang (2009), it states that, "Whenever the causes of climate change are discussed, fossil fuels top the list. Oil, natural gas, and especially coal are indeed major sources of human-caused emissions of carbon dioxide (CO_2) and other greenhouse gases (GHGs). But we believe that the life cycle and supply chain of domesticated animals raised for food have been vastly underestimated as a source of GHGs, and in fact account for at least half of all human-caused GHGs." Agricultural emissions are very complicated to quantify because there are so many different variables associated with livestock, from raising the animals to the consumption of the final product and every stage in between. For example, changes in land use play a role, as well as fossil fuel emissions associated with processing and transportation of agricultural products. Many estimations of the percentage of greenhouse gas emissions due to livestock may not account for many aspects of the complete life cycle of these products. Some of these aspects may be accounted for in another sector, or they may not be accounted for at all.

Some examples of sources Goodland and Anhang list as uncounted or misallocated are respiration by livestock, overlooked land use, and undercounted methane, as well as increased emissions in other sectors due to consumption of livestock products vs. alternatives to livestock products. For example, cooking of meat requires higher temperatures and longer cooking times than an alternative product to meat, or medical treatment that is carbon-intensive for millions of cases of disease caused by consumption of livestock products (Goodland and Anhang, 2009). These are sources that would not exist without consumption of livestock products, therefore arguably should be counted under agricultural emissions.

After compiling all sources of emissions relating to livestock, Goodland and Anhang conclude that at least 51 percent of all greenhouse gas emissions can be contributed to livestock. This is a much higher percentage than many other sources. The Food and Agriculture Organization of the United Nations (FAO) estimates only 18 percent attributed to livestock. This is a vast difference, but the FAO estimate does not account for many of the sources Goodland and Anhang mention. More research would need to be done to know if Goodland and Anhang are overestimating emissions, but it seems they make a strong point for focusing efforts to mitigate greenhouse gas emissions on agriculturally-related emissions.

Greenhouse Gases Associated with Beef

When looking at the GHGs that are associated with beef, there are three that account for the majority of emissions: carbon dioxide, methane, and nitrous oxide. Carbon dioxide is the GHG that is used to define a single unit of global warming potential and is often referenced when discussing climate change. When analyzing emissions related to the consumption of beef from a LCA perspective, there are numerous stages relating to pre- and post- production that produce carbon dioxide.For example, carbon dioxide emissions are associated with the conversion of land to grow feed for cattle as well as grazing pastures. The transportation of beef from farm-to-market also accounts for a large portion of carbon dioxide emissions related to beef consumption.

Methane has a global warming potential that is 25 times greater that carbon dioxide and is the major GHG emitted from ruminant production systems, with methane from enteric fermentation accounting for 12% to 17% of GHG emissions (Beauchemin et al., 2009). Methane emissions are also associated with the management of manure on farms with various factors, such as temperature, precipitation, and volume, controlling the total amount of emissions generated from each system.

Much like methane, nitrous oxide emissions, in relation to the consumption of beef, are primarily associated with enteric fermentation and waste management. While nitrous oxide is responsible for a much smaller portion of total emissions than either carbon dioxide or methane, it has a global warming potential that is 298 times that of carbon dioxide, making it an important aspect of the total emissions associated with beef production.

Solutions for Mitigation of Greenhouse Gases related to Beef Production

Emissions Related to Beef Production

There are a number of different methods used to measure the emissions related to the different stages in beef production. One method is the farm-gate emissions life-cycle analysis. Farm-gate emissions are those associated with the process and systems involved in feeding and raising the beef cattle before processing the meat. These emissions are broken down into four main categories: enteric fermentation, feed production, manure, and on-farm energy use. A total of 15.23 kg CO_2 equivalent per kg of edible meat at farm-gate (kgCO_2e/kgmeat) is produced during the farm-gate stage (Dunkley, 2013). The solutions explored in this paper will be focusing on the enteric fermentation and manure categories. According to the Environmental Working Group (EWG), enteric fermentation produced 7.51 kgCO_2e/kgmeat of methane (Dunkley, 2013). The EWG also found that manure produces emissions of 1.75 kgCO_2e/kgmeat of nitrous oxide and 0.59 kgCO_2e/kgmeat of methane (Dunkley, 2013). Though feed will be addressed, this paper will not address the feed production emissions. This paper will also touch on the emissions related to post farm-gate factors including processing and transport. These factors are responsible for emitting 3.73 kgCO_2e/kg meat (Dunkley, 2013).

Waste Management

Manure is responsible for 15.36% of the total farm-gate emissions of beef cattle, as methane and nitrous oxide are the GHGs related to this section of beef cattle emissions (Dunkley, 2013) . The terminology that refers to the waste management process within beef cattle is called the manure management continuum (MMC). This system is broken down into four different segments: generation within the beef cattle, animal housing, storage and treatment, and land spreading. This section of the paper will be focusing on the later three.

Another aspect to understanding cattle manure is the different types of manure. There are two main types: farmyard manure (FYM) and slurry. FYM is solid manure that is typically mixed with straw. Slurry is a form of liquid manure. FYM is produced when farm houses use bedding where they keep the cattle, whereas slurry is more prevalent in farm houses that have concrete or slabs instead of bedding. As this section will explain later, the emission rates will are dependent on the manure type. However, both types release methane and nitrous oxide, with methane as the larger contributor. The following will be a breakdown of the different methods that can be implemented to reduce methane and nitrous oxide emissions from manure.

Methane is emitted at all three of the stages. In animal housing, it is found mainly in the enteric fermentation process, which is caused by the microbes in the cattles' stomachs. There are also small emissions that come from slurry stored beneath the animal housing, and the frequent removal of this slurry can reduce the emissions. However, most of the methane emissions are released from the second of the MMC stages.

In the storage and treatment stages, there are many different factors that can be altered to reduce emissions. Some of these methods include covering the stored slurry, introducing additives to the FYM, and managing the temperature of the slurry or FYM (Chadwick, 2011). There was a recorded 13% decrease in emissions when the FYM is covered (Chadwick, 2011) and a 45% decrease in emissions when additives such as straw were mixed in at a 1:1 ratio (Chadwick, 2011). There were positive correlations between high temperatures and a higher emissions rate of methane. A possible solution to reducing methane emissions in the storage and treatment stages is to create a storage vessel that is covered, temperature regulated, and mixes in straw or other additives. There is no experiment or test conducted to conclude the validity of all three of these solutions working simultaneously, but there is potential for a large reduction in methane.

In the land spreading stage of the MMC, there is very little that can be done to reduce the emissions of methane except changing the feed type which will change the composition of the manure. However, this paper will go into further detail of this later. One unorthodox solution that is still in the testing and validation stages is the introduction of dung beetles in the soil in which manure is spread. These dung beetles have shown a reduction of methane of about 5 times less methane in soil (Pentilla, 2013).

Though methane makes up for 75% of manure emissions from cattle, nitrous oxide plays a big role in GHG emissions from beef cattle manure. Within the animal housing stage of the MMC, nitrous oxide is prevalent. One way to reduce 4-5 mgN_2O/day/cattle is to get rid of all bedding and use a slurry based system.

Within the storage and treatment stages, there are also a few solutions to reduce the emissions of nitrous oxide including covering the slurry, use additives for FYM or slurry, and introduce a slurry based system (Chadwick, 2011). Since some of these solutions contradict one another, the best method for reducing the emissions during this stage of the MMC is to introduce additives into a slurry besade system. This will complement the slurry based system in the previous stage of the MMC.

In the land spreading stage of the MMC, nitrous oxide emission reduction solutions are more prevalent and traditional compared to that of methane. Sticking along the same lines of implementing solutions for the storage and treatment stages, it is best to use methods that involve using slurry rather than FYM. Two solutions that can be used together to reduce nitrous oxide emissions is separating the slurry into a solid and liquid form and applying the slurry only in the spring (Chadwick, 2011).

Table 1 includes many different types of solution mitigation methods for nitrous oxide and methane at each stage of the MMC. Most of these are different and only applicable to its specific stage. With the combinations stated above, there can be a relatively large reduction in the emissions related to manure from cattle. However, one solution that is applicable to all of these stages for the reduction of both methane and nitrous oxide is modifying the feeding strategy. This suggests that the most effective and efficient way of reducing emissions related to manure is through feed selection.

<u>Feed Selection</u>

Animal and Dietary Factors

One way to reduce emissions from cattle is to change their feed type. Changes in the diet of a cow can have a beneficial effect on the composition of their waste products. Since enteric fermentation is one of the biggest contributors of cattle to GHG emissions, impacts on the amount of methane produced by cattle through this process could have substantial impacts. A study by Yan et al. (2009) examines the relationships between dietary and animal factors and methane output. These relationships can be very complicated, but in general, increasing the digestibility and metabolizability of feed will decrease methane emissions. Also, increasing the proportion of ash and/or crude proteins in the feed will decrease methane emissions. Increasing the live weight, dry matter intake, or gross energy intake will result in an increase in methane production. Table 2 (see Appendix) shows a more detailed breakdown of the impacts of different dietary and animal factors on methane production. Changing these variables in different combinations can also have varying effects. The same study provides equations to calculate methane output based on the different variables, which can be seen in Table 3 (see Appendix).

An experiment done by McGeough, et al. (2010) investigated the effects of feeding cattle maize harvested at different stages of maturity on methane output. Their conclusion was that more advanced maturity of the maize did not affect the performance of beef cattle, but decreased methane production. Allowing for maize to mature longer would have little impact on costs, and could have a positive impact on methane emissions. They also found that an ad litbium concentrate-based diet resulted in less methane emissions and faster body weight gain.

The Grass-fed vs. Grain-fed Controversy

There is much controversy over whether grass-fed cattle produce more or less methane than grain-fed cattle. There have been studies showing reductions in emissions, as well as studies showing increases in emissions. The study by Yan, et al. (2009) claims that there is a significant increase in the GHG emissions for an increase in forage proportion, meaning that grass-fed cows produce more methane, but many refute this claim. There are so many factors involved with the grass-fed vs. grain-fed arguments, that more in-depth studies considering the entire LCA of the two methods must be done. It also may vary based on the situation. Distances that the grass or grain feed must be shipped, or the availability of open grasslands to graze in may change the overall emissions associated with different cattle in different locations. There may be too many variables involved to make a general statement about which is better for all cattle.

Feed Production

GHG emissions from feed production were not considered in this study, but it is possible that the positive impact of changing feed type could be at least partially negated by an increase in emissions from feed production if the new feed type is more carbon-intensive to produce.

Selective Breeding

Currently, there are a lack of economic incentives for livestock farmers looking to reduce the GHG emissions associated with their product (McAllister, etc. 2011). This poses a problem for a range of methane mitigation strategies related to beef that cause undesirable reductions in production or result in an increased economic input for producers. One potential answer to this problem may lie within selective breeding, a strategy that may reduce emissions with little to no impact to current practices that are already in place.

For beef cattle, the digestion of feed is associated with the production of enteric methane. Within a herd of beef cattle, there will be a range of feed conversion efficiencies present. One measure of feed conversion efficiency is residual feed intake (RFI), a value relating the amount of feed consumed to the amount of beef produced. A low RFI is indicative of cows that efficiently convert feed into product (weight), while a high RFI represents an inefficient cow. In other words, for two cows of the same size and stature, the cow with a low RFI will require less feed, and will produce fewer emissions, than the equivalent cow with a high RFI (Basarab, etc. 2013). A study by G.C. Waghorn and R.S. Hegarty concluded that on average, a cow with a high RFI would produce 297 grams a day of methane while it’s low RFI counterpart would produce 260 grams a day (Waghorn, Hegarty, 2011). The relationship between RFI and methane production is the foundation of selective breeding as a solution to enteric methane emissions.

The RFI gene has been found to be moderately heritable (Basarab, etc. 2013), allowing producers of beef to breed their cattle in a manner that can result in sustained production associated with lower emissions and lower amounts of feed. Implementation of selective breeding requires minimal changes to a farm system, only requiring additional measurements of RFI within a herd. Although studies have shown positive results related to selective breeding, there are precautions that need to be taken to ensure a healthy population of cattle. As with any selective breeding program, it is important to maintain as much genetic diversity as possible outside of the few characteristics being selected for. Additionally, the importance of monitoring the health of the herd increases as more generations of cows are bred for a low RFI, the science behind this technique is fairly new and the potential for adverse gene selection associated with breeding for low RFI may only become noticeable after a number of generations have successfully bred.

Beef Processing

The emissions from the production of meat are usually associated with the various inputs that go into raising a cattle until it is ready to be processed, transported, and consumed. On the other hand, the emissions associated with the processing of cattle are mainly deduced from slaughtering the cattle and transporting the different cuts of meat from slaughterhouses to distributors of the finished product. Thus, a clear distinction must be made between the production and processing of cattle because production contributes the majority of greenhouse gas emissions associated with livestock production while processing of the cattle represents a mere 1.5% of total greenhouse gas emissions from livestock. Therefore, it is important to note that improving or changing the processing of cattle would have negligible impacts on total emissions flux compared to the rather significant effects of the other mitigation strategies on the production-side.

However, it is still valuable to understand which emissions come from the processing side of cattle production and where they come from. One of the main greenhouse gas emitters are slaughterhouses. Based on research done at two slaughter houses and farms in the UK and Brazil, slaughterhouse emissions are calculated by quantifying the emissions from energy consumption, allocating the emissions proportionally to the amount of carcass produced. The energy being consumed by the factory were divided into four subcategories: electricity (KWh/year), diesel fuel (L/year), kerosene (L/year), and wood (cubic meters/year). Electricity consumption is the largest producer of emissions out of the energy sources due to its production from a power plant. The diesel and kerosene fuels are the second largest producers of emissions due to the emissions associated with extraction and refinement of the fuels into their use phase forms. Lastly, wood consumption is the smallest producer of emissions because it releases negligible amounts of greenhouse gases upon combustion.

Based on the type of slaughterhouse run, different amounts of energy from each category were consumed. In the UK slaughterhouse, about 5.8 million kilowatt hours of electricity, 118,755 liters of diesel, and 55,269 liters of kerosene were consumed in a year while no wood was consumed. In the Brazil slaughterhouse, significantly less amounts of electricity were consumed at about 4.6 million kilowatt hours while no diesel or kerosene was consumed. Wood consumption for the Brazil slaughterhouse tallied up to about 2,300 cubic meters (Schroeder et al., 2012). As a result, the UK's slaughterhouse is evidently emitting much higher amounts of greenhouse gases compared to Brazil's slaughterhouse. In addition, Brazil produces most of its electricity via renewable sources so its slaughterhouse's electricity consumption is not only smaller than the UK's, but much cleaner and less of a burden to the environment. However, both slaughterhouses process roughly the same amount of carcasses at 19.7 million kg for the UK and 19.8 million kg for Brazil, emitting similar amounts of greenhouse gases with a conversion factor of 0.2 carbon dioxide equivalents per kilogram of carcass processed (Schroeder et al., 2012). Thus, the overall process of slaughtering meat has approximately the same environmental impact at the two countries, except the UK's energy consumption accounts for higher levels of emissions than Brazil due to their respective country's energy profiles. Notably, if the age of slaughter is reduced from 30 months to 24 months, a 13% reduction in emissions from enteric and waste management could be achieved.

The other greenhouse gas emitter is transportation. In the study done on the slaughterhouses in the UK and Brazil, the two types of transportation involved were marine and road travel. In general, Brazil had less distances to travel from farm to slaughterhouse, slaughterhouse to distribution center, and from the distribution center to the market. Thus, Brazil's meat production and distribution is generally more local than the UK. Yet, Brazil uses marine transport in addition to road transport while the UK does everything through road transportation so Brazil's transportation emissions are quite similar to the UK's due to the fact that a majority of their emissions come from transporting meat from the slaughterhouse to the destined port. In the case of the Brazilian slaughterhouse, the bone-free meat is considered as refrigerated type of meat transportation, so 30% more fuel consumption for the refrigerated transportation is accounted for (Schroeder et al., 2012). Consequently, the total payload weights of the meat in Brazil were much higher than the UK and the total carbon dioxide equivalent of transport emissions per kilogram of meat was higher for Brazil due to the added emissions from marine transportation.

Overall, the management of emissions coming from processing and transporting cattle has little effect on the overall emissions from cattle production. Yet, it is important to understand that emissions from meat processing directly depend on the the energy profile of the country that the slaughterhouse is in, the types of energy used to run the slaughterhouse, the types of transportation used to move the cattle and beef from farm to market, the distances travelled, and the payload weights of each mode of transportation. It is not in the slaughterhouse's power to change the energy profile of its respective country so that is not a valid area for change. However, the types of energy used to run the slaughterhouse is a valid area for emissions mitigation because a slaughterhouse can initially be built or gradually renovated to accommodate technologies that consume cleaner, less environmentally degrading sources of energy and fuel. For this reason, it is entirely in the meat producing company's hands to invest in operations and technologies that generate less greenhouse gases.

In terms of transportation, there is some capacity for change in which transportation methods are being used, the distances travelled, and the payload weights of the deliveries. Looking at the Brazilian slaughterhouse study, there are certain aspects of operation that are as efficient as they could be. For example, the Brazilian slaughterhouse transporting meat to ports via marine travel rather than air travel, which generates the highest levels of greenhouse gas emissions out of every transportation method possible, is the most efficient, least harmful method of transportation. Although the Brazilian company could cut off all exports to ports that are not reachable by land travel and only supply to local distributors, it is highly unlikely for a company to lose out on a large portion of their business for the sake of reducing emissions. Yet, it is not impractical to advise a meat producing company to seek out more local distributors or reduce the payload weight of each delivery. Both suggestions are valid ways of reducing transportation emissions because lighter payloads and shorter distances travelled increase the fuel economy of the vehicles and decrease the time needed to make deliveries.

Other Solutions to Mitigate Greenhouse Gases Associated with Beef

Is it enough?

With a projected exponential rise in population and a growing demand for beef, one begs to ask, " Will these beef cattle mitigation strategies be enough to cancel out the emissions?". Unfortunately, the answer is now. However, these mitigation strategies can help abate the overall effects and emissions of GHGs caused by beef cattle production. Therefore, there are a few other options that this paper briefly considers when it comes to beef cattle production.

Changes in Demand

Ultimately, the economic incentives to make environmentally responsible changes do not provide a strong argument for a company to invest in more efficient technologies, seek out more local business partners, or reduce the overall economy of scale of their business. Based on the basic principles of economics and business, a profiting organization seeks to generate the most revenue in the fastest period of time while incurring as little costs along the way as possible, regardless of any externalities that might come about. Hence, the negative externalities resulting from the cheapest methods of operation often damage the environment, and many times society, the most because the environment is usually never accounted for when companies make economic decisions. For example, a meat producing company may have a cattle farm located near a river bank that uses strong chemicals to protect its cattle and enhance feed. Over time, large amounts of rainfall and flooding could induce run-off to the local river that contains high enough concentrations of the chemicals to negatively affect the marine ecology of the river. The chemical run-off also has the potential to seep into the river that then feeds the local reservoir and drinking supply, directly jeopardizing the health of residents of surrounding towns. While the environment and society are being harmed by toxic chemicals used at the cattle farm, the farm receives none of the negative externalities from its chemical use so the meat producing company has every incentive to continue the use of the chemicals that help generate more profit from longer living cattle and enhanced feed.

However, if the owners of meat producing companies were to prioritize reducing greenhouse gas emissions from their operations, the feasibility of realistically implementing change is not an area of concern since all of the options provided are viable. Instead, the main obstacle preventing these changes from being made originate from the indifference of consumer demand for meat that is produced in an environmentally responsible manner. The meat producing company responds directly to consumer demand since consumers financially support the existence of the company in the first place. Thus, in order for environmentally responsible change to take place, it is up to the public and its consumers to place value on meat that is produced with the negative externalities to the environment and society in mind so that companies can change their practices to meet these demands. Otherwise, the only other way to reduce the emissions associated with meat production is to reduce the public's overall demand for meat products. To successfully make change in consumer demand for meat, understanding the complexity of global meat consumption is critical in identifying the challenges of meat consumption while assessing the potential leverage points that could affect consumer demand.

It is common economic knowledge that when supply goes down, demand and market price inevitably go up. Thus, in terms of global meat consumption, an exponentially increasing global population increases both demand and production of meat. According to the Food and Agriculture Organization, 2.3% more meat was produced between 2007 and 2008. They deem this number as a world supply and demand indicator of 1.1%. The FAO then suggests that in order to battle malnutrition and hunger, "20 g of animal protein per person per day or 7.3 kg per year should be provided. This can be achieved by an annual consumption of 33 kg lean meat or 45 kg fish or 60 kg eggs or 230 kg milk, respectively" (Yates-Doerr, 2012). The problem is that figures like this suggest that meat production and consumption are quickly rising, automatically suggesting an increase in demand for meat. This translation, offered by economists, takes the demand for meat as a foundational truth to build research upon. Yet, anthropologists and the public should instead explore how the notion of increased demand itself becomes established.

Another challenge is that many international organizations frame the need for meat as a nutritional need that can't be met with a vegetarian diet. They typically describe the nutrients found in meat to be of higher value and more readily absorbed into the human body. They also depict meat as an amalgam of nutrients that include water, proteins, amino acids, minerals, fats, vitamins, and other bioactive components so the nuances of human and animal relationships and the specific bodies being eaten become irrelevant (Yates-Doerr, 2012). Therefore, as price provides a universal equivalent for economists to study demand, the measurements of nutrients and calories provide nutritionists with the variables necessary to assess nutritional need. Specifically, the metabolic transfer of nutrients from one body to another is what matters, not the relationship between predator and prey so nutritional need varies from one individual to another.

Consequently, the translation and depiction of information to the public plays an important role in understanding the demand for meat. First, there must be a different way to speak of the demand for meat in terms of price and economics. While meat demand has been described as a function of price and money, there are also cultural demands that are measured by relationships rather than money. Decades of anthropological research show that eating is a means of making relationships with other people (Yates-Doerr, 2012). Thus, conceptualizing a demand for meat in a way that doesn't make demand a general abstraction that goes beyond the context in which it was materialized helps to keep demand tied to the relational interactions through which it comes into being. This would encourage the public to question how these demands emerged and how they are experienced, rather than take the increasing demand for meat as a given. Second, given the variations in practices and experience in eating, the international organizations working on the topic should recognize and incorporate these differences in their research. However, as research on the topic grows, academic researchers tend to study global networks instead of localized communities. As a result, their language, models, and analytic frameworks become increasingly reductive, suppressing the co-existence of the complexities of various eating practices. Information about meat has consolidated diverse practices into numeric expressions, where all differences are lost. Instead of interrelating each situation in which we consume, every discussion about meat demand is thought about in terms of universal equivalents such as money, calories, production, and so on (Yates-Doerr, 2012). Hence, the cultural differences in eating practices and consumption levels should be emphasized rather than grouping demand for meat into one giant system that can't be understood. Informing the public about their specific situations in terms of history, geography, culture, and value would have a greater influence in changing, and hopefully reducing, the emissions associated with meat production.

Push for Local

Buying beef that is produced locally has the potential to greatly reduce GHG emissions associated with transportation of beef products. If the products do not need to be transported long distances to reach consumers, the emissions associated with this could be greatly reduced. This may not apply in all cases, however. As usual, all factors in the life cycle of the product must be considered. For example, as mentioned earlier, if feed or other necessary entities for beef production need to be shipped longer distances in order for the beef to be produced locally, it may offset the positive benefits of limiting the transportation of the final product.

Food Policy

The current state of agricultural policies related to the mitigation of livestock emissions are relatively confusing, disorganized, and ineffective. With roughly 75% of global agricultural, non-carbon dioxide emissions being attributable to livestock production systems (Cooper et al., 2013), implementing policies for reducing livestock emissions will be necessary in order for emissions abatement systems to be environmentally conscious and cost efficient. Currently, many countries do not consider livestock emissions in their total agricultural emissions count, which poses as a large flaw in effective policy making because livestock emissions have been estimated to constitute up to 10% of global GHG emissions. Therefore, exploring domestic mitigation policy is a strong way to start identifying challenges associated with policy making and eventually force all major global emitters to reduce emissions.

At present, there are limited technological and farm-management strategies for controlling livestock emissions. These limitations raise significant policy issues regarding setting an appropriate point-of-obligation, minimizing transaction costs, and reducing the risks of non-compliance or misreporting (Cooper et al., 2013). Furthermore, the uneven effect that individual national mitigation policies have put into place so far raises issues of economic leakage and regression. As a result, many leaders have considered the approach of excluding livestock emissions from market-based mitigation measures. Realistically speaking, this approach is quite risky because it suggests that emissions be reduced without a strong price signal, which in turn requires mitigation technologies that are environmentally effective and also impose no net cost to livestock producers. This solution provides limited success in the short and medium term. Therefore, including livestock emissions in market-based measures has the potential to foster policy innovation, incentivize investment in technologies that reduce livestock emissions, and produce a wide range of mutual benefits.

A study done on New Zealand’s experience in designing and implementing a market-based policy that includes livestock emissions acts as a useful tool for other countries to learn from while forming their own mitigation policies. Primarily, it is essential to develop detailed inventory systems and methodologies that expose effective abatement strategies at the farm level. Second, significant amounts of public investment in the development of better technologies and farm-management practices helps to reduce emissions at a relatively low cost to producers. This would encourage producers to be less reluctant to market-based strategies. Lastly, implementing a strong policy framework for reducing livestock emissions requires unwavering political commitment and support. The resistance from agricultural lobbyist groups is inevitable so policy makers should aim to provide sufficient opportunities for agricultural consultation as well as a clear and realistic timeline for policy implementation. Again, a gradual approach with enough flexibility for revision and effectiveness would also help control producer resistance and encourage compliance. In effect, short term market-based policy implementation is unlikely to occur over a widespread basis. However, further policy experimentation and strong advocacy for reducing livestock emissions will help lead the movement towards effective mitigation and abatement.

Conclusions

In order to make a meaningful impact on greenhouse gas emissions, a multi-faceted approach must be taken. There are many aspects to greenhouse gas emissions, and they must all be considered when envisioning solutions. There is not one “magic bullet” solution that can be implemented to reduce these emissions. The only way to achieve the reductions in emissions that are necessary, there must be a series of smaller solutions that add up to a larger solution. This holds true specifically for agricultural emissions as well. There is not just one aspect of agriculture that holds the key to reducing emissions. Small reductions must be made along each step of the complete life cycle of a product. These reductions may seem to be negligible in the grand scheme of emissions, but when they are all added together they can have a huge impact. This must always be kept in mind when assessing impacts of individual solutions, and is the reason this paper outlines multiple solutions that can be used in combination to reduce greenhouse gas emissions from cattle.

This paper has outlined the reasons for wanting to reduce emissions associated with beef production, and offered several solutions that can be implemented to this end. These solutions include waste management solutions, as well as changes in feed type and selective breeding. There are also many possible solutions in beef processing that can be executed. With the increasing demand for beef products, these solutions may not be enough on their own. Other solutions that can be implemented include food policy, pushing for locally produced beef, and ultimately changing the public perception of and demand for livestock products, replacing them with non-meat substitutes that are healthier and less GHG intensive. All of these solutions together may have the potential to reduce GHG emissions from livestock, specifically beef, to the necessary levels to have a meaningful impact.

Appendix (tables and figures)

Potential mitigation methods for N_2O and CH_4 from the manure management continuum.

	Nitrous oxide	Methane
Animal house	• Modify feeding strategy • Adopt a slurry based system compared to a straw or deep litter based system	• Modify feeding strategy • Removal of slurry from beneath the house • Cooling slurry, *e.g.*, below the slatted floor
Manure stores	• Modify feeding strategy • Keep anaerobic (*e.g.*, cover and compact) • Adopt a slurry based system compared to a straw of deep litter based system • Add additional straw to immobilise ammonium-N	• Modify feeding strategy • Removal of slurry from the slurry store • Minimising slurry volume stored in summer months • Cooling slurry • Aerate solid manure heaps – composting • Anaerobic digestion • Enhancing crust formation
Land spreading	• Modify feeding strategy • Nitrification inhibition • Spring application of slurry • Integrate manure N with fertiliser N • Slurry separation? • Solid manure incorporation?	• Modify feeding strategy

Table 1: Potential mitigation methods for nitrous oxide and methane from the manure management continuum. (Chadwick, 2011)

Table 2 *Significant levels for the linear relationships between methane output and dietary and animal factors*[1,2]

	CH_4 (l/day)	CH_4/LW (l/kg)	CH_4/DMI (l/kg)	CH_4-E/GEI (MJ/MJ)
Live weight and feed intake				
Live weight (kg)	+***			
DM intake (kg/day)	+***	+***		
Organic matter intake (kg/day)	+***	+***		
GE intake (MJ/day)	+***	+***		
DE intake (MJ/day)	+***	+***		
ME intake (MJ/day)	+***	+***		−*
Feeding level	+***	+***	−*	−**
Dietary nutrient (kg/kg DM) or energy concentration (MJ/kg DM)				
Forage proportion			+*	+*
Ash	−*			
CP	−***			
GE	+*			
ME		−*		−***
Energy digestibility or metabolisability				
DE/GE		−*		
ME/GE		−**	−**	−**
ME/DE	−**	−**	−***	−***

[1] CH_4 or CH_4-E = methane or methane energy output; DM = dry matter; GE = gross energy; DE = digestible energy; ME = metabolisable energy; DMI = DM intake; GEI = GE intake; LW = live weight; Feeding level was calculated using maintenance energy requirement estimated from (Agricultural and Food Research Council (AFRC), 1993).
[2] +* or −* = positive or negative relationship with $P < 0.05$; +** or −** = positive or negative relationship with $P < 0.01$; +*** or −*** = positive or negative relationship with $P < 0.001$.

Table 2: (Yan, et al., 2009) This table shows the relationships between various animal and dietary factors and methane outputs. The pluses and minuses indicate a positive or negative relationship, respectively. Only the relationships with a significance level of 95% or greater are shown. The number of stars shown with the pluses and minuses indicate the significance level (described above).

Table 3 *Linear and multiple prediction equations for methane output weight using live weight or DMI together with other variables*

	Equations[1,2]	R^2	s.e.	Equation no.
CH_4 (l/day)	$= 0.378_{(0.092)}LW + 64.8_{(42.1)}$	0.26	40.0	(1a)
	$= [-0.325_{(0.135)} + 0.430_{(0.109)}NDF + 0.044_{(0.008)}CP/ME]\,LW + 130.0_{(12.8)}FL - 172.4_{(38.2)}$	0.66	27.6	(1b)
	$= [0.964_{(0.107)} - 4.078_{(0.361)}ME/GE + 2.623_{(0.343)}DE/GE]\,LW + 166.9_{(9.3)}FL - 194.7_{(25.0)}$	0.84	19.0	(1c)
	$= 35.1_{(2.6)}DMI + 14.7_{(17.7)}$	0.68	26.1	(2a)
	$= [31.0_{(6.5)} - 311.5_{(33.2)}ME/GE + 206.8_{(25.2)}DE/GE + 4.3_{(1.1)}ME]\,DMI - 13.7_{(12.9)}$	0.84	18.7	(2b)
	$= 1.959_{(0.141)}GEI + 8.8_{(17.2)}$	0.70	25.4	(3a)
	$= [1.635_{(0.345)} - 12.62_{(1.37)}ME/GE + 11.26_{(1.37)}DE/GE]\,GEI - 13.8_{(12.8)}$	0.84	18.7	(3b)
	$= [0.877_{(0.381)} - 14.66_{(1.34)}ME/GE + 13.55_{(1.32)}DE/GE + 0.457_{(0.126)}F/T + 4.153_{(0.997)}NDF - 7.47_{(1.60)}ADF]\,GEI + 0.8_{(14.9)}$	0.87	17.2	(3c)

[1]The subscripted data in parentheses are s.e. values.
[2]DMI = dry matter intake; *F/T* = forage DMI/total DMI (kg/kg); GE = gross energy; DE = digestible energy; ME = metabolisable energy; FL = feeding level (ME requirement for maintenance calculated from Agricultural and Food Research Council (AFRC) (1993)); GEI = GE intake (MJ/day); LW = live weight (kg); Unit for DMI is kg/day, for ADF and NDF, kg/kg DM and for DE, GE or ME, MJ/kg DM.

Table 3: Equations to calculate methane emissions based on live weight and dry matter intake, along with other animal and dietary variables.

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